DESIGNING AND CONSTRUCTION OF ROADS, SUBWAYS, AIRFIELDS, BRIDGES AND TRANSPORT TUNNELS

UDC 625.7/691.16

M. N. Panevin[1], Yu. I. Kalgin[2]

ORGANOMINERAL MIXES BASED ON AN ASPHALT CHIP FOR SURFACINGS AND SUBBASES OF HIGHWAYS

Ltd. «AVTODORIS»
Russia, Voronezh, e-mail: panevinn@mail.ru
[1]Engineer
Voronezh State Technical University
Russia, Voronezh, tel.: (473) 236-18-89, e-mail: kalgin36@yandex.ru
[2]D. Sc. in Engineering, Prof. of the Dept. of Construction and Operation of Highways

Statement of the problem. The problem of the development of organic-compounds characterized by the use of a mineral asphalt chip in part, to the device structural pavement layers.
Results. The results of the experiment and mathematical analysis to determine the physical and mechanical properties of organic-mineral mixes are shown. The operation of physical and mechanical and technological properties of organic-mineral mixes with different proportions of asphalt chip in the mineral part. The role of asphalt chip in improving the quality using organic-compounds. The optimum compositions of organic compounds using asphalt chips in the mineral part and the optimal characteristics of the materials for making them are presented.
Conclusions. The main factor influencing the characteristics of the organic mineral mix is the amount of bituminous emulsion making up a complex binder. Increasing the content of cement in the binder with a minimum content of the emulsion has a less significant effect on the properties of the mix. The ptimal content of asphalt chip is 40 % in the mineral part of the mix.

Keywords: asphalt concrete, asphalt chip, organic mixture, bituminous emulsion.

Introduction

Life cycle and transport and operational properties of highways can be improved by using modern technologies in their construction, reconstruction and maintenance [2, 5, 6, 12—15]. Organic and mineral mixes are one of the most effective materials used for roadways [3, 7, 10, 11].

The use of organic and mineral mixes in road construction has a few significant technological, economic and operational advantages [17—19] such as cutting-edge technology of material production to provide smoothness and roughness of a road surface, efficient and quick maintenance, reliability, possible use of local materials and secondary resources and primarily granular asphalt. Granular asphalt is a loose material consisting of mineral components and an organic binder making it good for secondary use. It becomes most cost-effective if used for asphalt concrete and organic and mineral mixes. The use of granulates of old asphalt in road construction in Russia allows one to lower a demand for mineral and binding materials and reduce the total costs of their components enabling asphalt and concrete wastes to be recycled as part of the environment-friendly effort [7—11].

According to the European Asphalt Pavement Association (EAPA), there is an annual increase in the use of granular asphalt for hot and cold asphalt concrete and bituminous mineral mixes [4, 8, 9]. In Japan 98 % of granular asphalt is used in asphalt concrete mixes [4].

1. Optimization of compositions and properties of organic and mineral mixes using a regression model of their mutual dependence. In order to develop the optimal compositions of organic and mineral mixes using complex binders and secondary road industry materials, an experiment was carried out using the methods of mathematical planning [1]. It is assumed that strength and operational properties of organic and mineral mixes are completely due to their composition. The components and their proportions in a mix may fluctuate as so do the conditions for solidification such as temperature and humidity. There might also be errors in measuring the water resistance or strength limit. Let us denote the numerical value of the characteristics in question as Y and its functional dependence on the parameters as $F(X_1, X_2, X_3)$. Random excitation in each of the experiments is expressed through an additive Z:

$$Y = F(X_1, X_2, X_3) + Z\,, \tag{1}$$

where according to the central limit theoreme, the random value Z has a normal distribution with the parameters $M(Z) = 0$ and $\sigma(Z) = \sigma$. Taking the mathematical expectation M from both parts, we get

$$M(Y) = M(F(X_1, X_2, X_3 + Z)) = F(X_1, X_2, X_3) + M(Z) = F(X_1, X_2, X_3)\,. \tag{2}$$

The last equality means that the initial functional bond $F\ (X_1, X_2, X_3)$ expresses not Y itseld but its mathematical expectation for the specified parameters X_1, X_2, X_3:

$$M(Y) = F(X_1, X_2, X_3)\,, \tag{3}$$

Such a dependence is regressional and the law $F(X_1, X_2, X_3)$ is a regression of Y along X_1, X_2, X_3. There is a well-developed method for obtaining a regression dependence based on experimental data, i.e. values of Y obtained for experiments with different combinations of independent factors X_1, X_2, X_3. The theory of experimental planning suggests that it is most reasonable to choose combinations of the parameters X_1, X_2, X_3 called plans or points to be used for regression approximation of a function using experimental values of Y identified for the plans [5].

2. Experimental methods. A method of planning a complete factor experiment suplemented with a few plans in the centre of the variation area. Varying elements are the following factors: X_1 is the content of a bituminous emulsion, %; X_2 is the content of cement, %; X_3 is the content of granular asphalt in the mineral part, % (Table 1). For all of the investigated characteristics of organic and mineral mixes, the mathematical model was searched for as a complete second-order polynomial of three variable with the removal of insignificant summands:

$$Y = a_0 + b_1x_1 + b_2x_2 + b_3x_3 + c_1x_1x_2 + c_2x_1x_3 + c_3x_2x_3 + d_1x_1^2 + d_2x_2^2 + d_3x_3^2 . \qquad (4)$$

In order to identify 10 initial parameters a_0, b_i, c_j, d_k for each of the characteristics Y three parallel series of 9 experiments were conducted. In each of the experiments there was a particular mix that was designed according to the guidelines of a complete factor experiment with three independent varying factors X_1, X_2, X_3.

The plan of the experiment and levels of varying factors were determined using the results of the preliminary experiments.

As a response

$$Y=Y(X_1,X_2,X_3)$$

for each point (X_1, X_2, X_3) of the plan of the experiment an arithmetic mean of the corresponding values of Y in three parallel series of the experiments. This improved the accuracy by 1.7 times. Changes in the factors of the experiment are ilustrated in Table 1.

Table 1

Changes in three independent factors

Characteristics	Code	Factors		
		X_1, content of a bituminous emulsion, %	X_2, content of cement, %	X_3, content of granular asphalt in the mineral part, %
Main level (X_{0i})	0	5	3.5	35
Variation integral (Δ_i)	ΔX	1.0	0.5	5
Upper level (X_i max)	$X_i = +1$	6.0	4.0	40
Lower level (X_i min)	$X_i = -1$	4.0	3.0	30

The plan of the experiment and natural values of the variables in each point of the plan are presented in Table 2.

Table 2

Plan of the experiment and natural values of the variables

Number of the plan	Plan of the experiment			Natural values of the variables		
	X_1	X_2	X_3	X_1, content of a bituminous emulsion, %	X_2, content of cement, %	X_3, content of granular asphalt in the mineral part, %
1	–1	–1	–1	4.0	3.0	30
2	+1	–1	–1	6.0	3.0	30
3	–1	+1	–1	4.0	4.0	30
4	+1	+1	–1	6.0	4.0	30
5	–1	–1	+1	4.0	3.0	40
6	+1	–1	+1	6.0	3.0	40
7	–1	+1	+1	4.0	4.0	40
8	+1	+1	+1	6.0	4.0	40
9	0	0	0	5.0	3.5	35

The major characteristics to be investigated were as follows:

— the compressive strength limit at the temperature 20 ºC of dry samples following 7 days of solidification (R_{20}, MPa) Y_1;

— the compressive strength limit at the temperature 50 ºC of dry samples following 7 days of solidification (R_{50}, MPa) Y_2;

— the average density, g/cm^3, Y_3;

— swelling (H, %) Y_4;

— water saturation (W, %) Y_5;

— the compressive strength limit at the temperature 20 ºC of water saturated samples following 14 days of solidification ($R_{20water}$, MPa) Y_6;

— the compressive strength limit at the temperature 20 ºC of dry samples following 14 days of solidification (R_{20}, MPa) Y_7;

— the compressive strength limit at the temperature 50 ºC of dry samples following 14 days of solidification (R_{50}, MPa) Y_8;

— water resistance ($K_в$) Y_9.

The compositions of the mixes, investigated characteristics and their values obtained as a result of the experiments are presented in Table 3—4. In Table 4 in brackets there are the values identified according to the designed regression models.

The experiment found a range of the factors to obtain the compositions of the mixes with the best physical and mechanical properties: the content of granular asphalt is 40 % in the minral part, third-order bituminous emulsion is 4 %, and 3—4 % of cement in a complex binder. According to these, the compositions were prepared to identify the properties of deformation and strength for road pavements.

Table 3

Compositions corresponding with 9 plans of the experiment

Material	Composition of a mix								
	№ 1	№ 2	№ 3	№ 4	№ 5	№ 6	№ 7	№ 8	№ 9
Crushed stone fraction 15—20 mm	12.50	12.50	12.50	12.50	3.50	3.50	3.50	3.50	3.50
Crushed stone fraction 10—15 mm	12.50	12.50	12.50	12.50	8.50	8.50	8.50	8.50	8.50
Crushed stone fraction 5—10 mm	15.00	15.00	15.00	15.00	18.00	18.00	18.00	18.00	18.00
Siftings	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	35.00
Granular asphalt	30.00	30.00	30.00	30.00	40.00	40.00	40.00	40.00	35.00
Cement	3.00	3.00	4.00	4.00	3.00	3.00	4.00	4.00	3.50
Water	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Emulsion	4.00	6.00	4.00	6.00	4.00	6.00	4.00	6.00	5.00
Total	108.50	110.50	109.50	111.50	108.50	110.50	109.50	111.50	110.00

Table 4

Results of the tests of the compositions corresponding with 9 plans of the experiment

Property (time of solidification)	Mix								
	№ 1	№ 2	№ 3	№ 4	№ 5	№ 6	№ 7	№ 8	№ 9
Strength limit at 20 °C, MPa (7 days)	1.66 (1.61)	1.25 (1.29)	1.72 (1.77)	1.95 (1.90)	2.77 (2.81)	2.01 (1.96)	2.25 (2.2)	1.75 (1.8)	2.35 (2.35)
Strength limit at 50 °C, MPa (7 days)	1.35 (1.30)	0.64 (0.69)	1.30 (1.36)	0.79 (0.75)	1.43 (1.47)	0.66 (0.64)	1.56 (1.54)	0.68 (0.71)	1.15 (1.06)
Swelling, % (14 days)	–0.69 (0.56)	–0.38 (–0.43)	–0.88 (–0.84)	–0.88 (–0.76)	0.01 (0.03)	–0.03 (0.11)	–0.22 (–0.23)	–0.18 (0.16)	–0.02 (–0.36)
Water saturation, % (14 days)	2.89 (2.64)	2.70 (2.98)	3.42 (3.60)	3.42 (3.27)	3.06 (3.22)	3.69 (3.56)	3.82 (3.56)	2.93 (2.82)	3.43 (3.26)
Strength limit at 20 °C in the water saturated state, MPa (14 days)	2.82 (2.87)	1.90 (1.86)	2.88 (2.87)	1.88 (1.96)	2.65 (2.64)	2.12 (2.19)	2.44 (2.54)	2.18 (2.19)	2.28 (2.39)
Strength limit at 20 °C, MPa (14 days)	1.99 (2.07)	1.44 (1.51)	2.48 (2.58)	1.98 (2.03)	2.44 (2.56)	1.97 (2.0)	2.69 (2.69)	1.99 (2.14)	2.84 (2.2)
Strength limit at 50 °C, MPa (14 days)	1.61 (1.61)	0.77 (0.88)	1.85 (1.89)	0.86 (0.93)	1.46 (1.52)	0.85 (0.80)	1.97 (1.98)	1.03 (1.02)	1.61 (1.33)
Water resistance	1.42 (1.44)	1.32 (1.29)	1.16 (1.13)	0.95 (0.97)	1.09 (1.04)	1.07 (1.12)	0.91 (0.96)	1.09 (1.04)	0.80 (0.8)

Note: in brackets are the values found according to the designed regression models.

The results of the experiment are identified in Table 5.

Table 5

Deformation and strength properties of the compositions of organic and mineral mixes

Component composition of a complex binder	Cement — 3 %, bituminous emulsion — 4 %			Average value	Cement — 4 %, bituminous emulsion — 4 %			Average value
Failure load, N	3.5	3.6	3.7		3.9	4.4	4.0	
Height of the sample, cm	7.2	7.1	7.1		7.2	7.2	7.2	
Diameter of the sample, cm	7.1	7.2	7.1		7.2	7.2	7.1	
Crack resistance using the tensile for a crack at the temperature 0 °C and deformation speed 50 mm/min, MPa	0.69	0.70	0.73	0.71	0.75	0.85	0.78	0.79
Failure load at 50 °C, N	19.5	18.2	22.6		18.4	20.4	17.3	
Time of loading, sec	5	5.5	6.1		6	5.5	7	
Loading speed, mm/min	50	50	50		50	50	50	
Average performance of the deformation of the samples in the test using the Marshall scheme, J	2442.50	2502.50	3451.08		2755.50	2807.75	3031.00	
Failure load at 50 °C, N	4.91	5.27	6.43		9.5	8.5	8.5	
Time of loading, sec	5	4.4	4		4	3.9	3.9	
Loading speed, mm/min	50	50	50		50	50	50	
Average performance of the deformation of the samples in the test for one-axial compression, J	613.75	579.70	643.00		950.00	828.75	828.75	
Coefficient of the internal friction	0.90	0.91	0.93	0.91	0.85	0.88	0.89	0.87
Compressive strength limit at 50 °C, MPa	1.23	1.32	1.61	1.39	2.38	2.12	2.12	2.21
Shear adhesion, MPa	0.25	0.26	0.31	0.27	0.52	0.44	0.43	0.46

Considering the influence of the components of a complex binder in the range of optimal values of the characteristics of organic and mineral mixes on the shear resistance, note that the coefficient of internal friction is insignificantly higher than for a smaller content of cement in a complex binder. As the content of cement in a complex binder goes up by 3 to 4 % per 100 % of the mineral part, the shear adhesion increases by 1.7 times. Crack resistance using the strength limit with a crack at the temperature 0 °C and the deformation speed of 50 mm/min in the range of optimal values of the characteristics of the compositions of organic and mineral mixes is within 0.7—0.8 MPa. The effect of an extremely high content of cement per a unit is insignificant.

Conclusions

1. Water saturation of compositions in the investigated area ranges from 2.80 to 3.80 %, which corresponds with the range specified in the GOST (ГОСТ) 30491-2012. Smaller water saturation corresponds with a high content of a bituminous emulsion and an extremely low content of cement in a complex binder as well as granular asphalt in the mineral part.

2. The density of the samples in the investigated area of factors is within 2.35—2.38 g/sec^{m3}. Deviations of the characteristics are not significant. A smaller average density corresponds with compositions containing the upper boundary of granular asphalt. Thus a higher density corresponds with compositions containing the lower boundary of granular asphalt in the mineral part of a mix.

3. All of the investigated compositions are prone to swelling in the entire range of changes of the factors.

4. The strength of the compositions in the water saturated state is within 1.9—2.9 MPa. It is mostly affected by a composition of a complex binder and least by a content of granular asphalt in the mineral part of the mix. The best value of a characteristics corresponds with the investigated factors as follows:

— content of granular asphalt is 40 % in the mineral part,
— that of third-class bituminous emulsion is 4 %,
— that of cement is 3—4 % in a complex binder.

5. The major factor that influences the strength characteristics of an organic and mineral mix in the range of normal temperatures is the amount of a bituminous emulsion in the composition of a complex binder in the entire range of the investigated recipe characteristics allowing the strength to change from 1.4 to 2.7 MPa. This is also true following 7 as well as 14 days of solidification of the samples. A higher content of cement in a complex binder with a minimum content of an emulsion improves the characteristics. A higher content of granular asphalt in the mineral part has a more insignificant effect on changes in the characteristics.

6. The strength characteristics of an organic and mineral mix at higher temperatures depend on the amount of a bituminous emulsion in a complex binder in the entire range of the investigated factors, which changes the strength at the temperature 50 ºC of dry samples I nthe range of 0.8 to 2.0 MPa. A higher value of the characteristics corresponds with the upper boundary of a content of cement in a complex binder as well as a higher amount of granular asphalt in the mineral part of an organic and mineral mix.

7. The optimal recipe values of the compositions of organic and minerla mixes are as follows:

— content of granular asphalt ranges from 30 to 40 % in 100 % of the mineral part;

— content of a third-class bituminous emulsion is 4 %, that of cement is 3—4 % in a complex binder over 100 % of the mineral part.

References

1. Gmurman V. E. *Teoriya veroyatnostey i matematicheskaya statistika* [Probability theory and mathematical statistics]. Moscow, Vysshaya shkola Publ., 1998. 480 p.
2. Gorelyshev N. V. *Asfal'tobeton i drugie bitumomineral'nye materialy* [Asphalt and other materials bitumomineraljnykh]. Moscow, Mozhaysk-Terra Publ., 1995. 176 p.
3. Gorelysheva L. A. Organomineral'nye smesi v dorozhnom stroitel'stve [Organo-mineral mixtures in road construction]. *Avtomobil'nye dorogi: obzornaya informatsiya*, 2003, vol. 3, 107 p.
4. Dymov S. *Tekhnologii ispol'zovaniya asfal'togranulyata (RAP) v goryachikh i teplykh smesyakh: prezentatsiya* [Technology the use of asphaltgranulate (RAP) in hot and warm mixes: presentation]. Available at: http://maxconf. ru/event/files/48
5. Kalgin Yu. I. *Dorozhnye bitumomineral'nye materialy na osnove modifitsirovannykh bitumov* [Road bitumomineraljnykh materials based on modified bitumen]. Voronezh, Izd-vo Voronezh. gos. un-ta, 2006. 272 p.
6. Kalgin Yu. I., Strokin A. S., Tyukov E. B. *Perspektivnye tekhnologii stroitel'stva i remonta dorozhnykh pokrytiy s primeneniem modifitsirovannykh bitumov* [Perspective technologies of construction and repair of road surfaces with the use of modified bitumen].]. Voronezh, Voronezhskaya oblastnaya tipografiya, 2014. 224 p.
7. Karamysheva V. M., Gorelysheva L. L. Primenenie vlazhnykh organomineral'nykh smesey pri stroitel'stve i remonte avtomobil'nykh dorog [The use of wet organic-mineral mixtures in the construction and repair of roads]. *Avtomobil'nye dorogi: obzornaya informatsiya*, 1989, vol. 4. 53 p.
8. Karelin D. Yu. *Sovremennye sposoby primeneniya asfal'tovogo granulyata: prezentatsiya OOO «Virtgen-Internatsional'-Servis»* [Modern methods of application of the asphalt granulate: presentation of LLC "virtgen-international-Service"]. Available at: http://maxconf.ru/event/files/48
9. Lupanov A. V., Silkin V. V., Sukhanov A. S., Gladyshev N. V. *Primenenie asfal'tovogo granu-lyata pri proizvodstve asfal'tobetonnykh smesey na ABZ* [The use of asphalt granulate in the production of asphalt mixes at the plant]. Available at: http://maxconf.ru/event/files/48
10. Ol'khovikov V. M. [The use of organic binders in the reconstruction of roads with gravel and macadam coating]. *Trudy GPRosdornii* [Works GP Rosdornii], 2000, vol. 10, pp. 104—110.
11. Panevin N. I. *Opyt ispol'zovaniya asfal'togranulyata v organomineral'nykh smesyakh s bitumnoy emul'siey: prezentatsiya OOO «Avtodoris»* [Experience in the use of asphaltgranulate in organic mixtures with bitumen emulsion: presentation of LLC "Avtodora"]. Available at: http://maxconf.ru/event/files/48
12. Wolff & Muller f. Asphalt concrete with reduced dust. Patent Bel'gii, no. 755694, 1971.
13. Dorius Carl B., Jones George M., Morse Park L. Cold-laid bituminous paving materials, Patent SShA, no. 3074807, 1963.
14. Anderton Benjamin A. Cold-rollable paving mix, Patent SShA, no. 2629669, 1953.

15. Huchenrojter Ju., Vjorner T. *Asfal't v dorozhnom stroitel'stve* [Asphalt in road construction]. Moscow, ABV-press Publ., 2013, 450 p.

16. Hochbelastete Straβendecken Europäische Argumente fur SMA. Asphalt, 1999, no. 3, pp. 21—27.

17. Holl A. Dünne Schichten im Kalteinbau. Asphalt, 1995, no. 6, pp. 18—21.

18. Maccarone S. Cold Asphalt Systems as an Alternative to Hotmix. Asphalt Review, 1995, v. 14, no. 1, pp. 19—24.

19. Suss G., Karolewski U. Erhohung der Anfangsgriffigkeit von Asphaltdeckschichten-Ergebnisse einer Pilotstudie. Asphalt, 1998, no. 4, pp. 28—32.

20. Wang Zhenjun, Wang Qiong, Ai Tao. Comparative study on effects of binders and curing ages on properties of cement emulsified asphalt mixture using gray correlation entropy analysis. Construction and Building Materials, 2014, vol. 54, no. 15, pp. 615—622.

21. Seredin P. V., Glotov A. V., Domashevskaya E. P., etc. Structural and spectral features of MOCVD AlxGayIn1-x-yAszP1-z/GaAs (100) alloys. SEMICONDUCTORS, 2012, vol. 46, iss. 6, pp. 719—729.